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Short communication

The Danube so colourful: A potpourri of plastic litter outnumbers fish larvae in Europe's second largest river

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ABSTRACT

Previous studies on plastic pollution of aquatic ecosystems focused on the world's oceans. Large rivers as major pathways for land-based plastic litter, has received less attention so far. Here we report on plastic quantities in the Austrian Danube. A two year survey (2010, 2012) using stationary driftnets detected mean plastic abundance (n = 17,349; mean ± S.D: 316.8 ± 4664.6 items per 1000 m^{-3}) and mass (4.8 ± 24.2 g per 1000 m^{-3}) in the river to be higher than those of drifting larval fish (n = 24,049; 275.3 ± 745.0 individuals. 1000 m^{-3} and 3.2 ± 8.6 g 1000 m^{-3}). Industrial raw material (pellets, flakes and spherules) accounted for substantial parts (79.4%) of the plastic debris. The plastic input via the Danube into the Black Sea was estimated to 4.2 t per day.

1. Introduction

Plastic, the lightweight and long-lived material, has become a serious environmental hazard (Thompson et al., 2009). The annual global production of the organic polymer has rapidly increased from 1.7 to 280 million tonnes within the last 60 years (Plastics Europe, 2012) resulting in the accumulation of plastic litter in virtually all habitats (Browne et al., 2011). Marine systems are sinks for pre- and post-consumer plastic and the multifaceted negative impacts of plastic pollution on wildlife (reviewed in Cole et al., 2011; Derraik, 2002; Oehlmann et al., 2009) as well as several aspects of debris composition, distribution and abundance have been described here (reviewed in Ryan et al., 2009). Although accumulation of plastic in the ocean is prevalent, there is scarce data on plastic inputs in the oceans (Law et al., 2010). Marine plastics originate from ship or land-based sources (Coe and Rogers, 1997) with the latter to be of greater relevance (Andrady, 2011). A significant portion of the terrestrial plastic is transported to the seas by rivers. Nevertheless, quantifications of plastic loads in rivers found in primary literature are minimal (Moore et al., 2011). Realistic estimations of the plastic flow from rivers to oceans are very important in helping to raise the awareness of the sources of plastic debris and ultimately to drive measures to reduce it.

In this article, we present results from a two-year (2010, 2012) survey on plastic litter transport in Europe's second largest river, the Danube. The main aim of the study was to categorize and to quantify drifting plastic items. In a second step we compare plastic abundance and plastic mass in the river with those of ichthyoplankton (drifting fish larvae and juveniles). Adverse health effects may arise when small fish confuse plastic particles with food items (zooplankton, fish eggs) and ingest them (Carpenter et al., 1972). Finally we give a rough estimate of the input of plastic litter via the River Danube into the Black Sea. To our knowledge, this is the first report on plastic transport in a large river.

The whole study was embedded in a scientific project that highlights larval dispersal and the conservation of riverine fish populations. All sacrificed individuals were handled according to applicable regulations and used for comprehensive analysis (Lechner et al., 2013b).

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2. Methods

2.1. Study site

The study was conducted in a free flowing stretch of the Austrian Danube between Vienna and Bratislava. All sampling sites were situated within the "Danube Alluvial Zone National Park" which preserves the last remaining major wetlands environment in central Europe (http://www.donauauen.at). Here, the average river width is 350 m and the discharge at mean flow is 1930 $m^3 s^{-1}$. Featuring the world's most international river basin (19 countries, 800.000 km^2, 81 million people), the Danube is a special case study regarding conservation and management issues (Sommerwerk et al., 2009). As the main tributary (input of 6444 $m^3 s^{-1}$ at mean flow) and major nutrient pathway, the Danube directly affects the Black Sea (BSC, 2009). Beside eutrophication, the vulnerable ecosystems of this continental water face an increasing threat of plastic litter pollution (Topcu et al., 2013). Inputs from land-based sources have gained less attention but are supposed to be high, especially via the Danube River System (Lebreton et al., 2012).

2.2. Sampling

The sampling procedure has been accurately described elsewhere (Lechner et al., 2013b). Briefly, we utilized stationary conical driftnets (0.5 m diameter, 1.5 m long, 500 μm mesh) that were fixed to iron rods driven into the riverbed and sampled the top 0.5 m of the water column. Nets covered 60% of the water column in more than 75% of all cases. The mesh size we used is in the range of other studies that quantified suspended plastics (reviewed in Hidalgo-Ruz et al., 2013). A flowmeter (2030R, General Oceanics®, Miami) was attached to the lower third of each net entrance to measure the volume of filtered water. In this volume-reducing approach, the filtered sample (containing plastics, fish larvae, organic debris and other items) is collected in a jar attached to the net-end and can be taken to laboratory for further processing.

Duplicates (2010) and triplicates (2012) of driftnets were simultaneously exposed at three (2010) to four (2012) sampling stations along both river margins with maximum distances of 1 km between the single stations and 25 m between the shoreline and driftnets. In 2010, we sampled circadian (24 h) periods with hourly intervals between single sample events. In 2012, sampling started 2 h before sunset (according to ephemeris) and was continued in hourly intervals until midnight. Collecting day and night samples was essential in consideration of realistic comparisons between ichthyoplankton and plastics abundance: larval fish drift is known to exhibit a distinct diurnal rhythm with nocturnal peaks in individual numbers (Pavlov et al., 2008). Therefore, exclusive daytime sampling would have underestimated fish densities by far. The sampling period (Apr–Jul) was chosen to comprise the entire drift season (Lechner et al., 2013a). Before preservation in 96% alcohol, all fish were overdosed (500 mg/l) with the anesthetic tricaine methanesulfonate.

2.3. Sampling processing

In the laboratory, plastic items and fish larvae were separated from the samples in a two-step process. Each sample was suspended in a water bath and a density separation (buoyant plastic particles and larvae with intact swim bladders were removed), was followed by a careful visual sorting of the remaining material by the naked eye.

2.4. Characterization and quantification of plastics

All plastic pieces and larvae were counted. A subsample ($n = 500$) of fish larvae was taken and all individuals were weighed to the closest 0.01 g (moist mass). Each plastic particle was allocated to one of the categories shown in Fig. 1. *Pellets*, *spherules* and *flakes* characterize different types of industrial raw material that serve as precursors for plastics production. The category "*others*" encapsulates all other pieces and fragments of plastic consumer products. A subsample ($n = 500$) of each category was taken and all containing items were weighed to the closest 0.01 g and measured to the closest 0.01 mm (Zeiss® Axio Imager M1 with Axio Vision 4.8.2 software for image analysis). Referring to the size-ranges of the defined groups, the collected plastic may be termed mesodebris (2–20 mm; *pellets*, *flakes*, big *spherules*, *others*) or microdebris (<2 mm, small *spherules*) (Ryan et al., 2009) though different nomenclatures have been used in the literature (Cole et al., 2011; Hidalgo-Ruz et al., 2013). The abundance of fish larvae and plastics, below named drift density, is given as individuals and items per volume of filtered water (1000 m^{-3}). Additionally mass values of plastic and larvae are given in grams per volume (1000 m^{-3}). Means of larval and plastic drift densities were compared using Mann–Whitney *U*-tests (SPSS 20.0®, IBM Corp., Armonk, NY, USA). The plastic input (grams per 1000 m^{-3}) into the Black Sea (BS) was estimated using the simple formula,

$$\text{Input}_{BS} = \text{Load}_{NP} \times F_P$$

where the average plastic load (all categories combined) in the National Park (Load_{NP}) at mean flow (data derived from both sampling years) is multiplied by a factor reflecting the downstream increase in population in the Danube basin (F_P) (ICDPR, 2009; http://www.icpdr.org). Refining the result of this approximation by exploring the potential of applying an appropriately adapted sediment transport model coupled with hydrodynamic simulations (e.g. Tritthart et al., 2011) is envisaged for a future detailed study.

3. Results and discussion

In both years 951 drift samples were taken (day: 293, night: 658) containing a total of 24,049 young fish and 17,349 plastic items.

Fig. 1. Categories of drifting plastic items in the River Danube: pellets (mean weight ± S.D: 26.14 ± 4.5 mg; mean diameter ± S.D: 4.13 ± 0.48 mm), flakes (w: 2.23 ± 1.51 mg; d: 2.81 ± 0.51 mm), spherules (w: 4.45 ± 3.26 mg; d: 2.91 ± 0.65 mm), others (w: 51.6 ± 139.83 mg; d: 15.01 ± 12.58 mm).

Table 1
A: Mean drift densities (items. 1000 m^{-3}) with standard deviations (S.D), as well as minimum (min) and maximum drift densities (max) are shown for different types of plastic and total plastics. Percentages show the contribution of single categories to the overall drift density. **B**: same information is given for plastic mass (g 1000 m^{-3}).

Category	2010				2012			
	Mean ± S.D	Min	Max	%	Mean ± S.D	Min	Max	%
A								
Pellets	34.9 ± 146.1	0.0	2135.2	3.7	9.3 ± 27.3	0.0	232.6	17.0
Flakes	80.1 ± 317.6	0.0	3568.9	8.5	5.7 ± 9.1	0.0	55.0	10.4
Spherules	693.1 ± 8299.9	0.0	138219.3	73.9	2.0 ± 8.7	0.0	136.3	3.6
Others	129.4 ± 235.5	0.0	2922.0	13.8	38.0 ± 47.2	0.0	465.3	69.0
Total	**937.6 ± 8543.8**	**0.0**	**141647.7**		**55.1 ± 75.4**	**0.0**	**744.5**	
B								
Pellets	0.9 ± 3.8	0.0	55.8	8.4	0.2 ± 0.7	0.0	6.1	11.0
Flakes	0.2 ± 0.7	0.0	8.0	1.6	0.0 ± 0.0	0.0	0.1	0.6
Spherules	3.1 ± 36.9	0.0	615.1	28.4	0.0 ± 0.0	0.0	0.6	0.4
Others	6.7 ± 12.2	0.0	150.8	61.5	2.0 ± 2.4	0.0	24.0	88.1
Total	**10.9 ± 43.6**	**0.0**	**697.5**		**2.2 ± 3.0**	**0.0**	**30.2**	

Both plastic densities and composition displayed distinct differences between sampling years (Table 1): not only the overall plastic density but also the mean and maximum drift densities of all categories were clearly higher in 2010, with industrial plastics comprising 86% of the total load. Other plastic litter revealed higher drift densities in 2012 (69% of the total load) and dominated plastic mass in both years due to the higher mean weight. Combining both years of observation the average plastic load of the river Danube amounts to 316.8 ± 4664.6 items per 1000 m^{-3} (79.4% industrial, 20.6% others) which equates to 4.8 ± 24.2 g per 1000 m^{-3} (29.7% industrial, 70.3% others). Pre-production plastics have been found to increasingly contribute to the plastic debris problem in marine habitats (Barnes et al., 2009). Our results identify the Danube as a transport route for plastic raw material and suggest that environmental pollution by this category is a crucial factor in river systems as well. Considerable inter and intra-annual differences in drift densities may be attributed to the pulsed, accidental release of the material during processing, packaging and transport (Moore, 2008). There are dozens of plastic production sites and an unknown number of processing companies in Germany and Austria. Some of them are situated adjacent to the Danube (http://www.plasticseurope.org). Furthermore, inland navigation is a popular transport mode and cargo ships frequently cruise the Danube (on average 1000 per month at the sampling sites; Kucera-Hirzinger et al., 2009).

In both years of observation, more plastic items than fish larvae were drifting in the Danube at daytime (Fig. 2). However, differences in plastic versus ichthyoplankton were statistically significant only in 2010 ($n = 182$, $Z = -3.22$). Increasing larval densities after dusk exceeded those of plastic in 2010 ($n = 99$, $Z = 4.59$) and 2012 ($n = 559$, $Z = 13.94$). Overall, the Danube transported more plastic in 2010 and more ichthyoplankton in 2012 ($n = 669$, $Z = 13.19$). Pooling all samples, mean larval densities in the Danube were 275.3 ± 745.0 individuals per 1000 m^{-3} and hence lower than mean plastic densities. In addition, average biomass of drifting larval fish was lower than plastic mass in both years (Table 2). The fish to plastic ratios indicate a high availability of harmful, unsuitable food items to potential consumers (Moore et al., 2001).

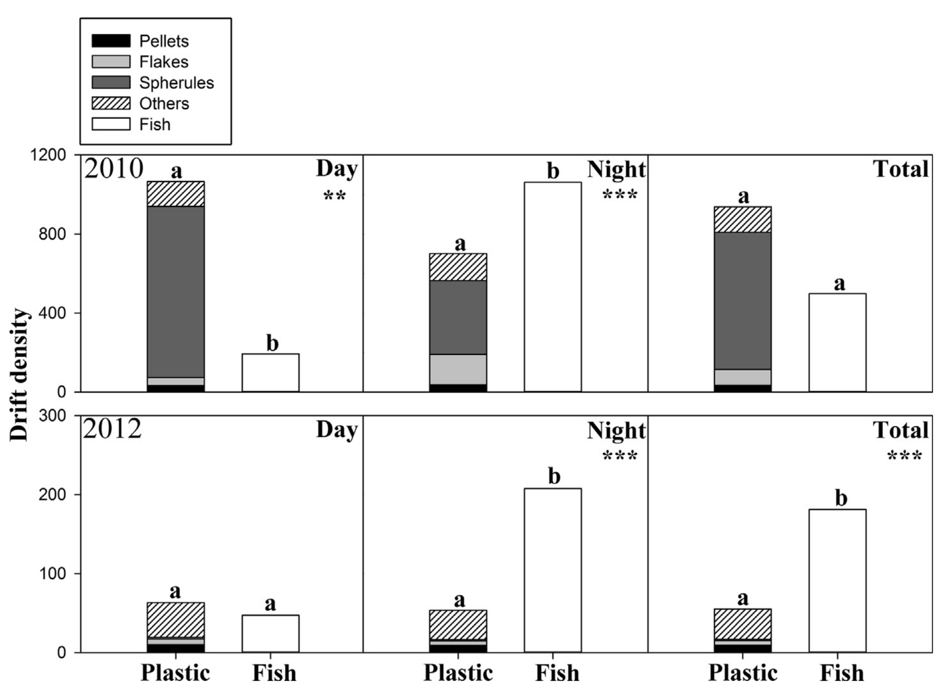

Fig. 2. Mean drift densities of plastic and larval fish at daytime (left), during night (mid) and in total (right) are shown for 2010 (upper series) and 2012 (lower series). Asterisks indicate high significant (**; $p < 0.01$) and highly significant (***; $p < 0.001$) differences.

Table 2
Mean plastic mass and mean biomass of larval fish are given in grams per 1000 m^{-3} of filtered water.

	2010	2012	Total
Fish	5.8 ± 14.8	2.1 ± 3.2	3.2 ± 8.6
Plastic	10.9 ± 43.6	2.2 ± 3.0	4.8 ± 24.2

The input of plastic litter in the Black Sea via the Danube is estimated to average about 7.5 g per 1000 $m^3\ s^{-1}$ at mean flow (6444 $m^3\ s^{-1}$). This yields a total entry at the mouth of 48.2 g per second (Fig. 3), 173.6 kg per hour, 4.2 t per day and 1533 t per year. This is more than the estimated total amount of plastic in the North Atlantic Gyre (1100 t; Law et al., 2010). For several reasons, our values must be regarded as an underestimation of the total plastic load into the Black Sea:

1) The amount of filtered microplastics is negatively correlated with the mesh size. Norén (2007) found the abundance of small plastic fibres in a 80 μm net to be five orders of magnitude higher than in a 450 μm net. Therefore we suppose microscopic fragments (<500 μm) to be underrepresented in our samples.
2) The same holds true for large floating items (>5 cm), which did not enter driftnets through the small gap between net-frame and water surface. But especially large material contributes to the plastic mass in oceans (Lattin et al., 2004).
3) Compared to Germany and Austria, all other neighbouring countries of the Danube feature lower standards in their wastewater and sewerage treatment (http://www.icpdr.org). Their potentially higher contributions to the Danube's plastic load should considerably cumulate and increase the average input at the mouth.

Plastic is the dominant debris in the Black Sea with a high percentage of items (47%) sourcing in neighbouring countries (among them several of the Danube basin), potentially introduced by river currents (Topcu et al., 2013). There is rare information about land based litter sources and the "Development and improvement of the existing monitoring system to provide comparable data sets for pollutant loads (from direct discharges and river inputs)" is a high priority task of the "Black Sea Strategic Action Plan" (BSC, 2009). Giving first answers on abundance and composition of plastic litter in the river Danube we hope to serve the cause and help to strengthen the enforcement of national and international regulations on land-based pollution sources (i.e. Operation Clean Sweep®, http://www.opcleansweep.org) Furthermore, our results shall give impetus to continuative studies on freshwater plastic pollution. All harmful consequences of plastic contamination described in marine systems (ranging from ingestion of plastic particles by a wide range of organisms to introduction of alien species which raft plastic litter) may operate in rivers and lakes and deserve closer attention.

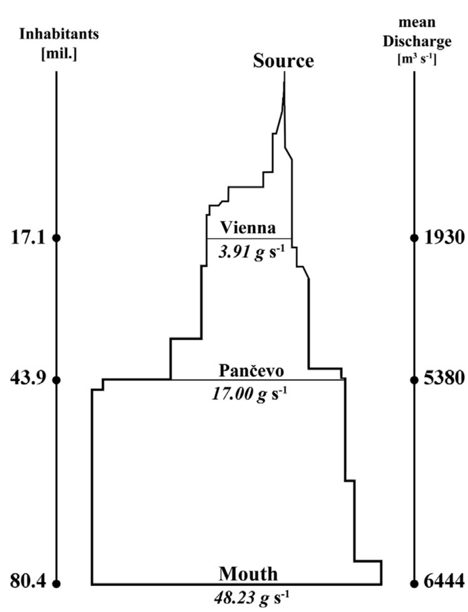

Fig. 3. Average plastic load (g s^{-1}) of the River Danube at mean flow. Redrawn after Liepolt (1967).

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